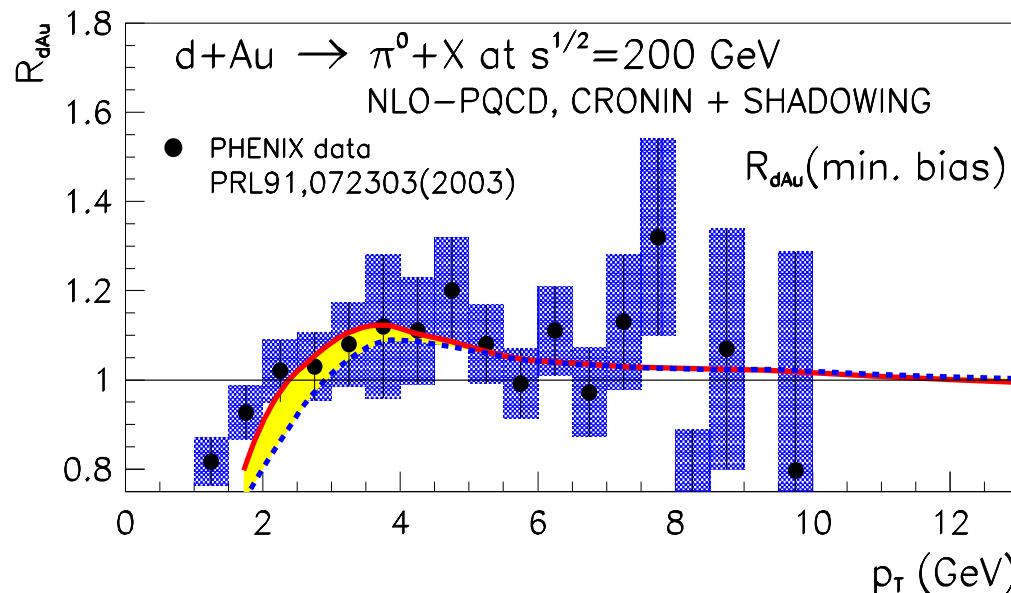


Cronin Effect in dAu Collisions at RHIC Energies



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17th International Conference on Ultra-Relativistic
Nucleus-Nucleus Collisions (Quark Matter 2004)
10-17. January 2004. Oakland – CA – USA

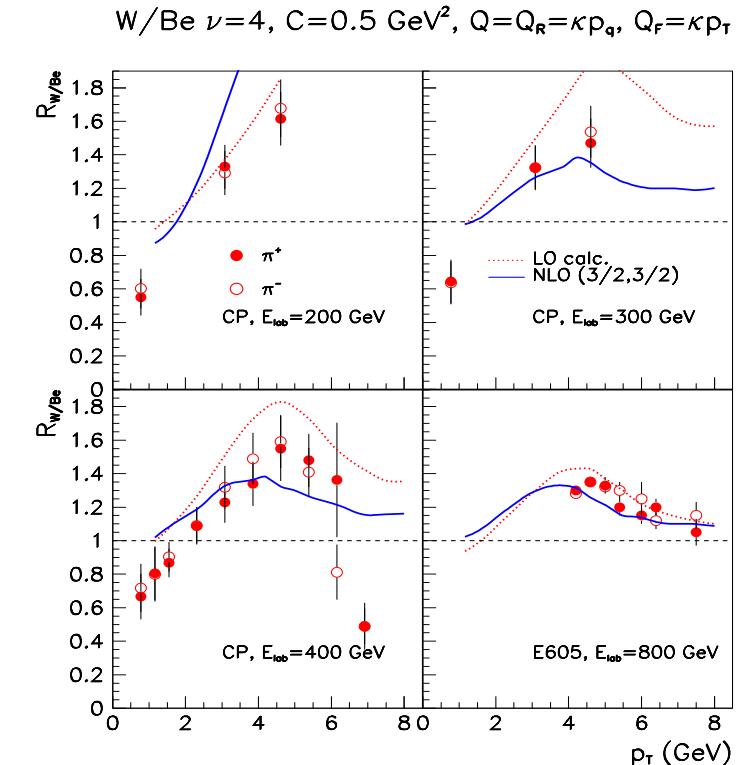
Motivation – Cronin Effect, R_{AA}

Cronin effect: increased particle production in $3 \text{ GeV} < p_T < 6 \text{ GeV}$ momentum window (1975)

”increased” means more particles are produced in pA than expected from N_{bin} scaled pp collisions

Nuclear modification factor

→ measuring Cronin effect:



$$R_{AA} = \frac{1}{N_{bin}} \frac{dN_{AA}/dy \, d^2p_T}{dN_{pp}/dy \, d^2p_T}$$

D. Antreasyan *et al.* Phys. Rev. D19, 764 (1979)

C.N. Brown *et al.* Phys. Rev C54, 3195 (1996)

Y. Zhang *et al.* Phys. Rev C65, 034903 (2002)

Questions and Program

Does initial or final state effects generate π suppression?

Hadronic: \Rightarrow final state effects

Partonic: \Rightarrow initial state effects (stronger shadowing)
 \Rightarrow final state effects (jet quenching)

I. pQCD calculations – with nuclear shadowing only?

II. Cronin effect in pQCD improved parton model

Multiple scattering in saturated Glauber picture

k_T -broadening \rightarrow Cronin effect reproduction at $y = 0$

R_{dAu} results for dAu PHENIX data

III. Calculations for dAu BRAHMS data at $y = 3$

IV. Summary – Outlook

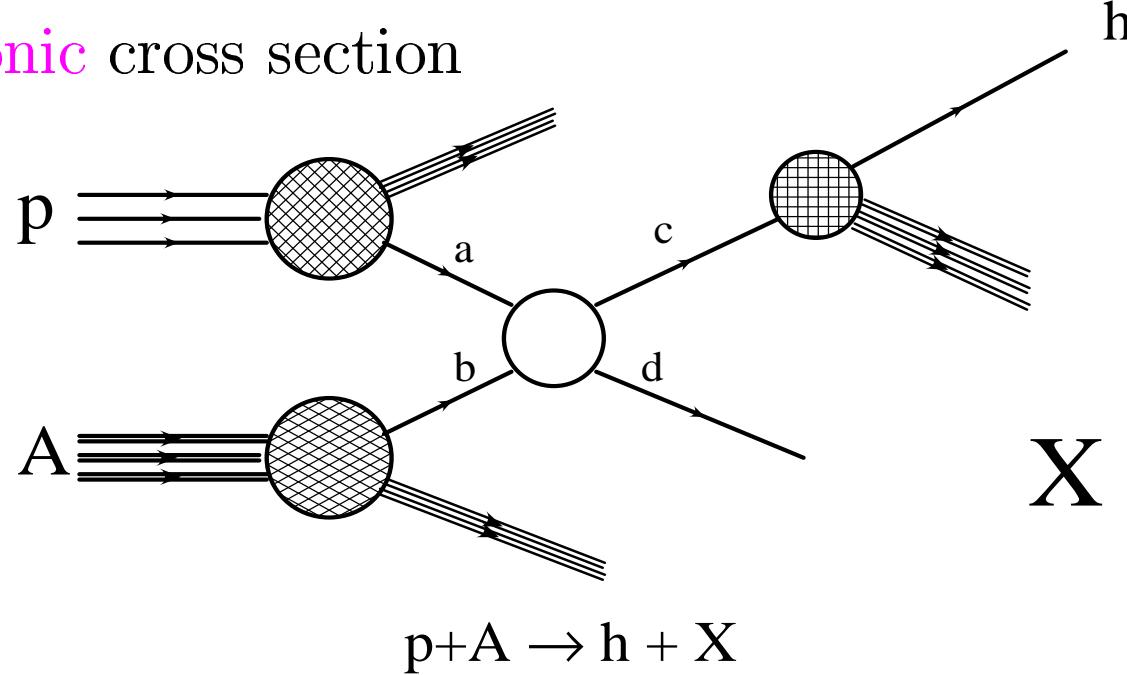
I/1. pQCD Improved Parton Model for pA Collisions

$$E_\pi \frac{d\sigma_\pi^{pA}}{dp_\pi^3} \sim f_{a/A}(x_a, Q^2; k_T, b) \otimes f_{b/p}(x_b, Q^2; k_T) \otimes \frac{d\sigma^{ab \rightarrow cd}}{dt} \otimes \frac{D_{\pi/c}(z_c, \hat{Q}^2)}{\pi z_c^2}.$$

$f_{a/A}(x_a, Q^2; k_T, b)$: Parton Dist. Function (PDF), at scale Q^2

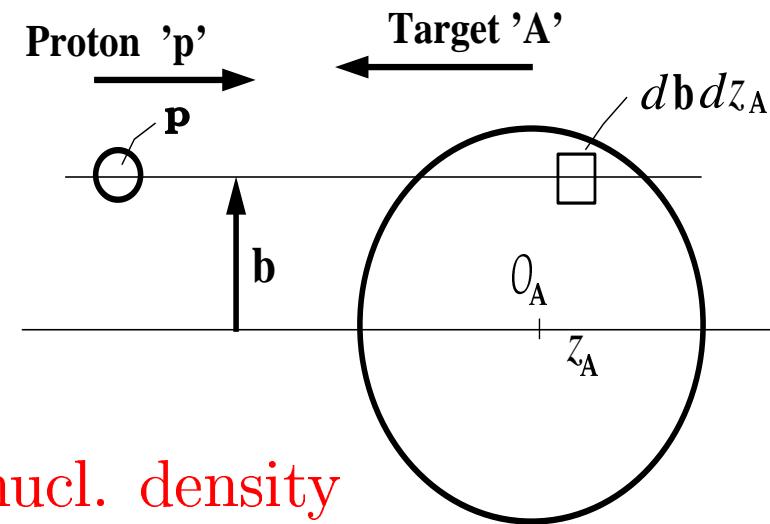
$D_{\pi/c}(z_c, \hat{Q}^2)$: Fragmentation Function for π (FF), at scale \hat{Q}^2

$\frac{d\sigma^{ab \rightarrow cd}}{dt}$: Partonic cross section



I/2. Collision Geometry and Shadowing in $pA \rightarrow \pi$

$$E_\pi \frac{d\sigma_\pi^{pA}}{d^3 p} = \int d^2 b t_A(b) \ f_{a/A}(x_a, Q^2; \dots) \dots$$



(a) Nuclear thickness function:

$$t_A(b) = \int dz \rho(b, z) \text{ and normalized as:}$$

$$A = \int_0^{b_{max}} t_A(b) d^2 b, \text{ where } \rho(b, z) \text{ nucl. density}$$

(b) Shadowing – PDFs are modified inside the nucleus

$$f_{a/A}(x, Q^2; b) = S_a^A(x, b) \left[\frac{Z}{A} f_{a/p}(x, Q^2) + \left(1 - \frac{Z}{A}\right) f_{a/n}(x, Q^2) \right]$$

$S_a^A(x, b)$: b -dependent or independent shadowing function;

HIJING: S. Li, X.-N. Wang: Phys.Letts. **B527**, 85(2002)

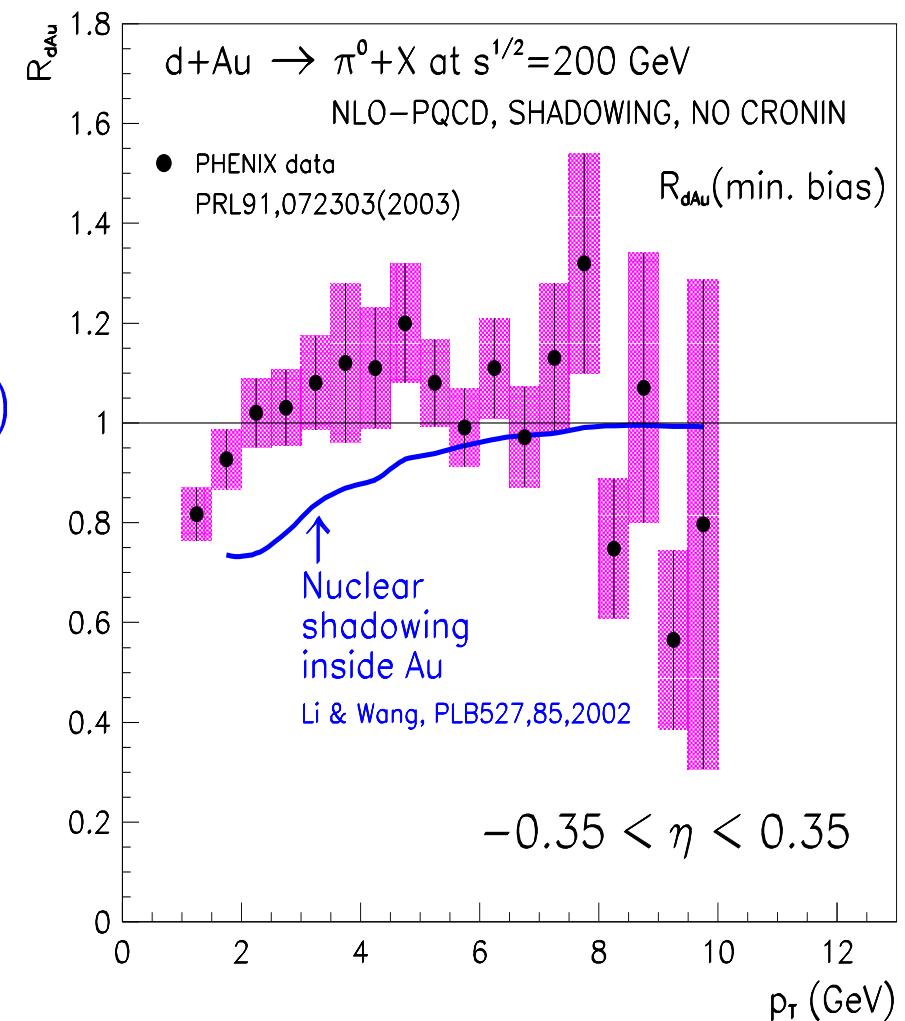
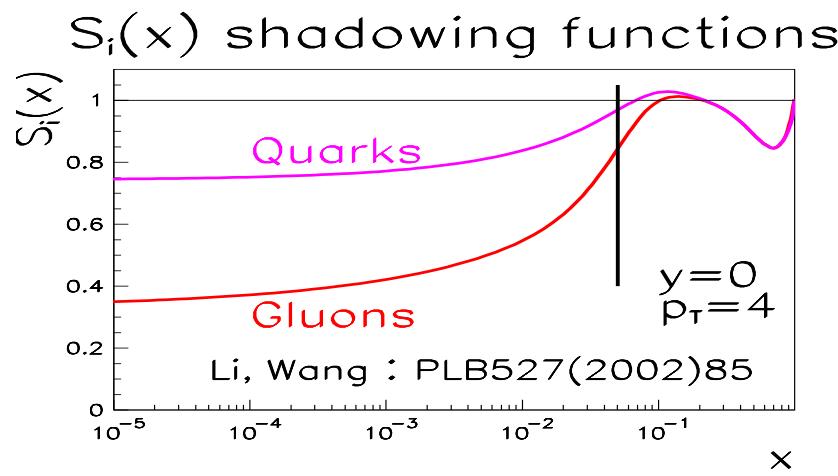
A atomic- and Z the proton number

I/3. Nuclear Modification Factor for dAu at $\sqrt{s} = 200$ GeV

- PHENIX data at $y = 0$

Phys. Rev. Lett. 91, 072303 (2003)

- Shadowing inside nucleus is small effect at PHENIX at $y = 0 \iff$ we are at moderate- x region ($\langle x \rangle \sim 0.05$)



Is multiscattering able to enhance the calculated yield?

II/1. Theoretical Model – Reproduction of Cronin Effect

Introducing intrinsic k_T for colliding partons

Phenomenological assumption: PDFs are modified
 1 dimensional PDFs are changed to 1+2 dimensional ones

$$dx f_{a/p}(x, Q^2) \rightarrow dx d^2 k_T g_{pp}(\vec{k}_T) f_{a/p}(x, Q^2)$$

where $g(\vec{k}_T)$ is a Gauss distribution function :

$$g_{pp}(\vec{k}_T) = \frac{e^{-\vec{k}_T^2/\langle k_T^2 \rangle}}{\pi \langle k_T^2 \rangle} \quad \text{and} \quad \langle k_T^2 \rangle = \frac{4 \langle k_T \rangle^2}{\pi}$$

Baseline $\langle k_T^2 \rangle$ values for pp : Phys. Rev. **C65** 034903 (2002)
 $\langle k_T^2 \rangle$ value agrees with measured values by PHENIX

II/2. Reproducing Cronin Effect – Multiple Scattering

Saturated NN collision numbers (in $pA \rightarrow \pi$)

- improve the Glauber model:

$$E_\pi \frac{d\sigma_\pi^{pA}}{d^3 p} = \int d^2 b \ t_A(b) E_\pi \frac{d\sigma_\pi^{pp}(\langle k_T^2 \rangle_{pA}, \langle k_T^2 \rangle_{pp})}{d^3 p}$$

$$\langle k_T^2 \rangle_{pA} = \langle k_T^2 \rangle_{pp} + C h_{pA}(b)$$

Total broadening = pp baseline + nuclear broad.

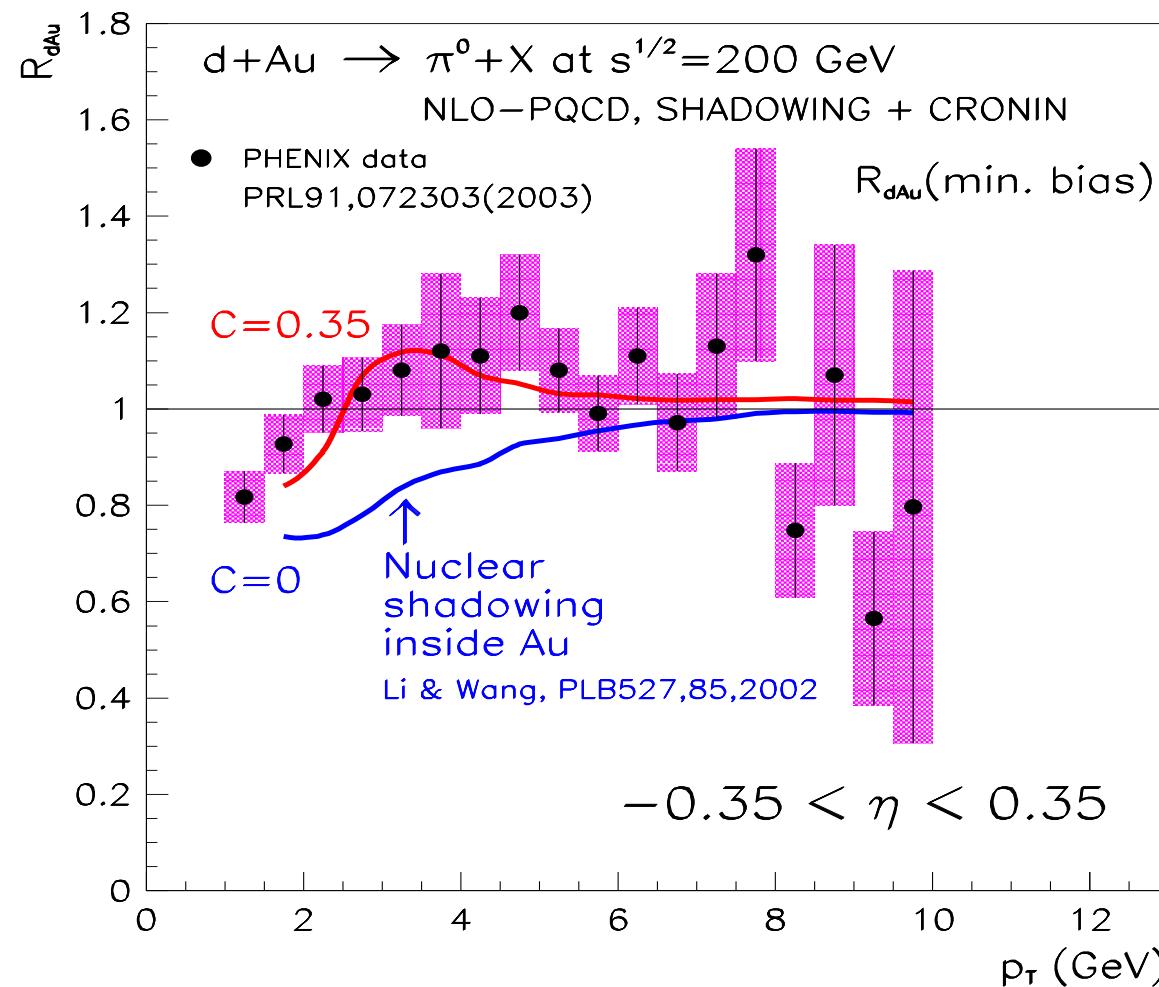
See details in PRC65 034903 (2002) and [hep-ph/0212249](#)

$h(\nu_A(b) - 1)$: number of effective NN collisions $\nu_{max} = 3 - 4$

C : (average mom. broadening)² / coll. $C \approx 0.35 \text{ GeV}^2$

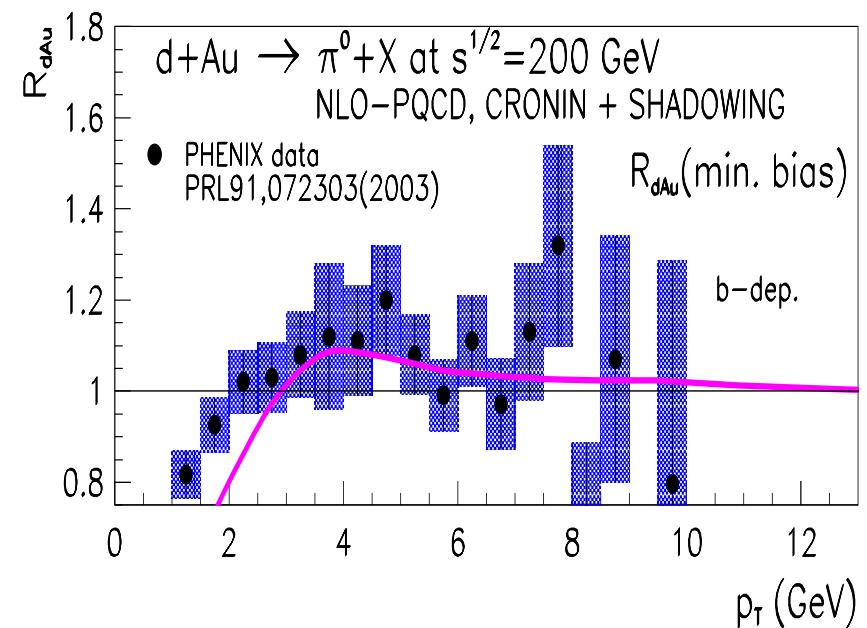
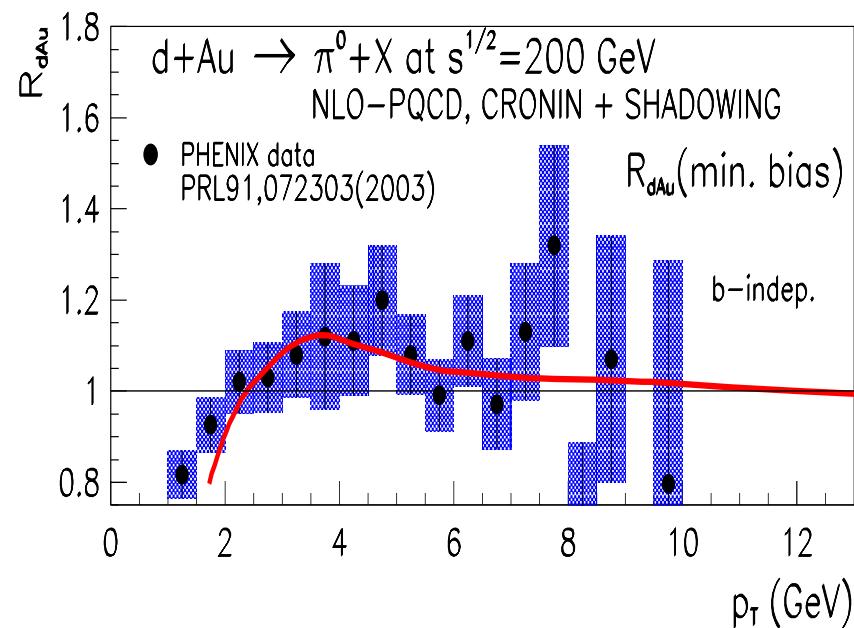
$t_A(b)$: nuclear thickness function

Cronin Effect with shadowing and multiscattering in dAu collision at PHENIX ($\sqrt{s} = 200$ AGeV)



HIJING (b -dep.) shadowing, $\nu_{max} = 4$, $C_{sat} = 0.35$, $y = 0$

Cronin effect with b-independent (left) and b-dependent (right) shadowing in dAu collision at PHENIX



NO quenching is assumed \Rightarrow NO suppression in dAu

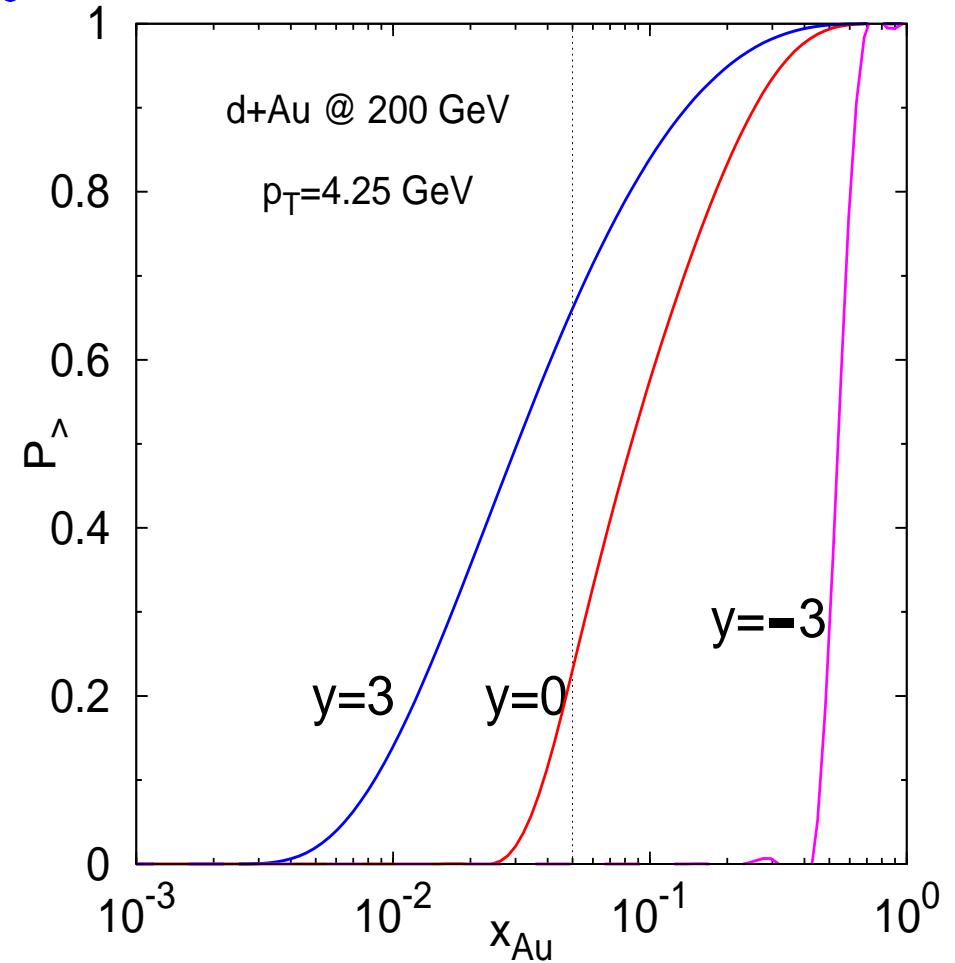
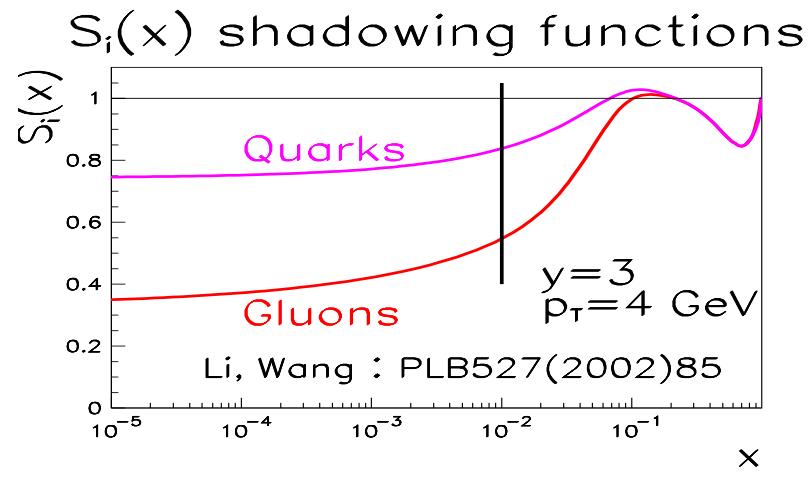
See details in: P. Lévai, G. Papp, G.G. Barnaföldi, G. Fai: [nucl-th/03006019](https://arxiv.org/abs/nucl-th/03006019)

III. Calculations with Shadowing at Larger Rapidity

- Cumulative probability

$$P_>(x_{Au}) = \frac{\int_0^{X_{Au}} d\sigma(x') dx'}{\int_0^1 d\sigma(x') dx'}$$

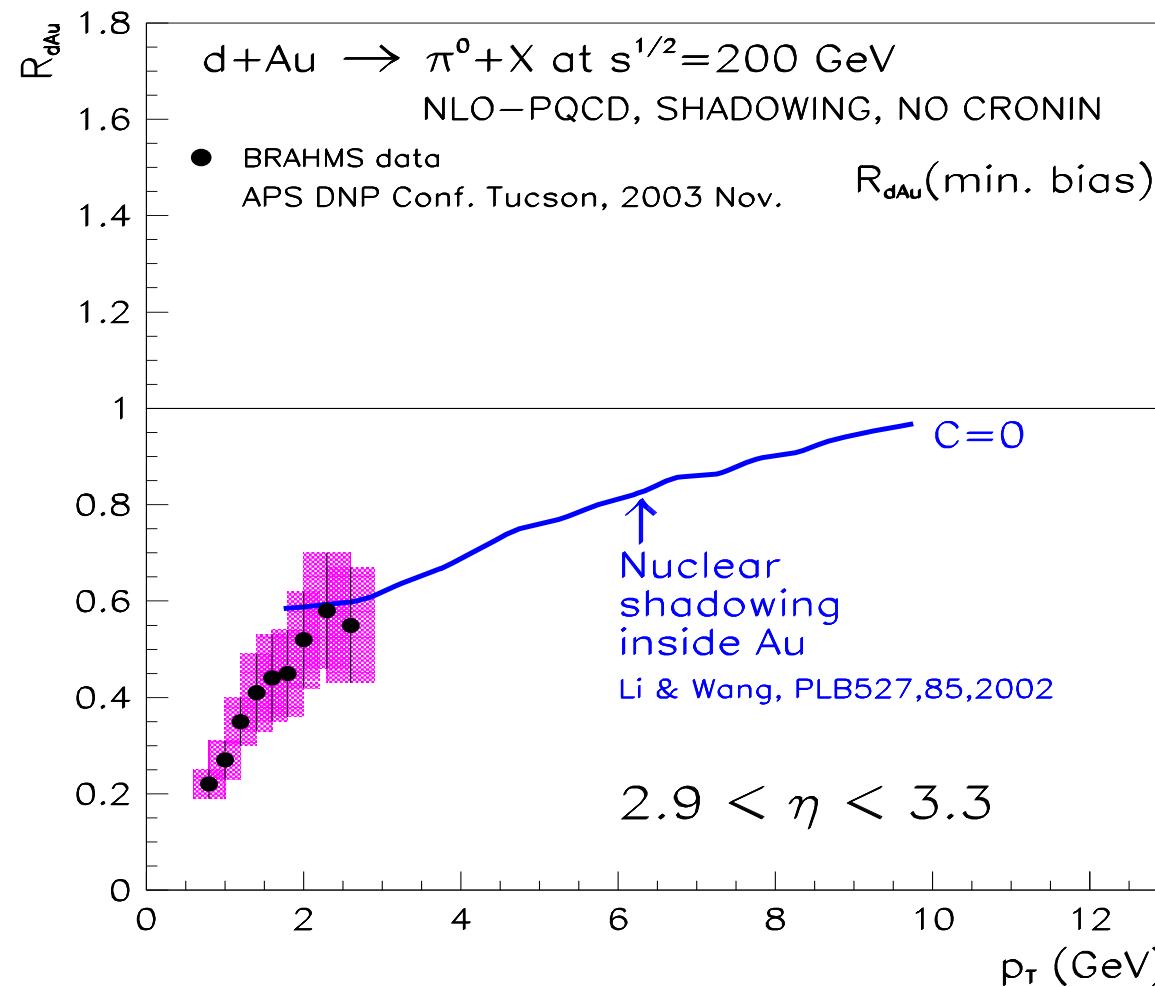
- substantial contribution from higher- x region



$p_T = 4$ GeV and $y = 0 \Rightarrow \sim 5\%$ suppression

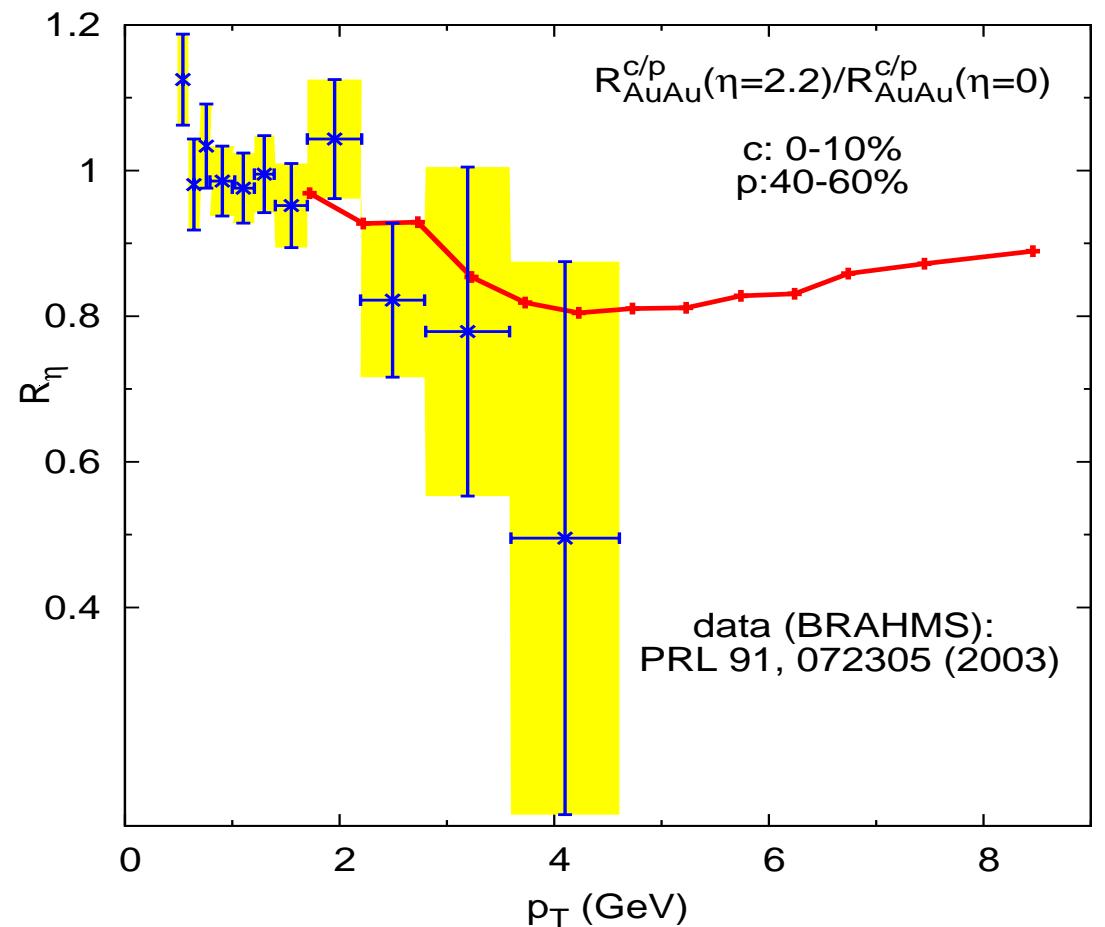
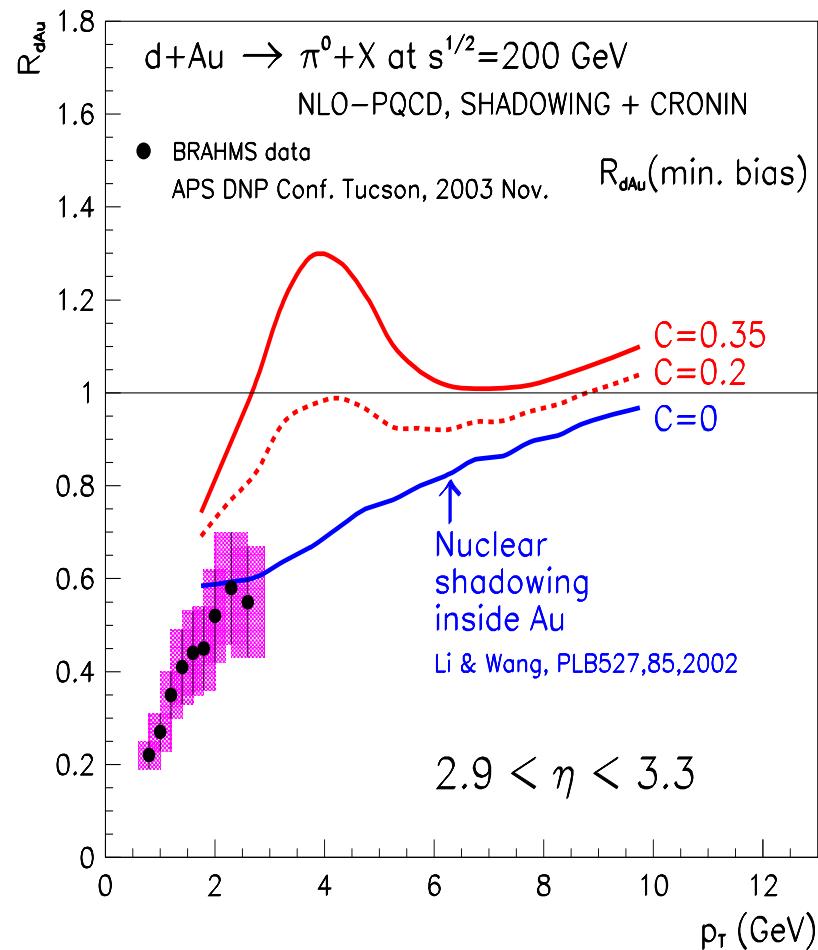
$p_T = 4$ GeV and $y = 3 \Rightarrow \sim 30\%$ suppression

BRAHMS data in dAu collision at $\sqrt{s} = 200$ AGeV calculation with shadowing only



HIJING (b -dep.) shadowing, NO Cronin ($C_{sat} = 0$), $y = 3$

BRAHMS data in dAu collision at $\sqrt{s} = 200$ AGeV calculation with shadowing + CRONIN



HIJING (b -dep.) shadowing, $\nu_{max} = 4$, $C_{sat} = 0 - 0.35$, $y = 3$

Summary – Outlook

Goal: Reproducing the Cronin effect in $dAu \rightarrow \pi$ at RHIC:

I. Cronin effect reproduction at $y = 0$

- Baseline: pp results for intrinsic- k_T , $\langle k_T^2 \rangle$
- HIJING shadowing
- Multiple scattering with saturated Glauber picture
 - ⇒ PHENIX data well reproduced
 - ⇒ NO suppression, NO need for extra shadowing

II. Results for $dAu \rightarrow \pi$ at $y = 3$

- Determining the efficiency of multiscat. at $y > 0$,
see more details on G. Papp's Poster: P31
- Looking forward to experimental data at larger p_T
 - ⇒ Present model is consistent with experimental data

Related Publications

G.G. Barnaföldi; P. Lévai; G. Papp; G. Fai

Proc. of Erice '03 hep-ph/0312384 (2003)

Proc. of ICNRM '03 nucl-th/0307062 (2003)

R_{dAu} at RHIC nucl-th/0306019 (2003)

Submitted to Heavy Ion Phys. nucl-th/0206006 (2002)

Phys. Rev **C65**, 034903 (2002) hep-ph/0109233

Nucl. Phys **A698**, 627 (2002) hep-ph/0104021

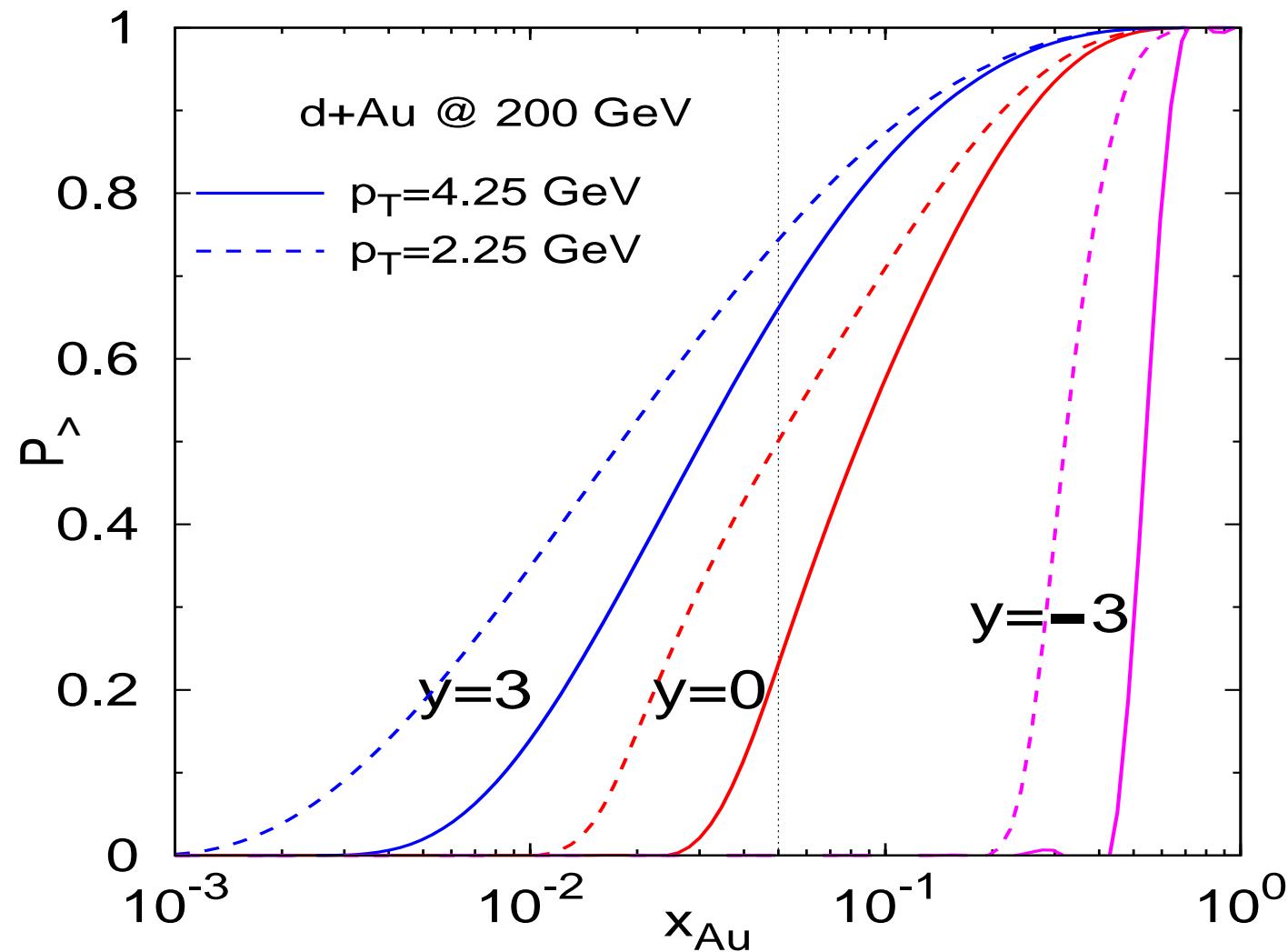
Nucl. Phys **A698**, 631 (2002) hep-ph/0104035

JHEP PRHEP-hep2001/242 (2001) hep-ph/0111211

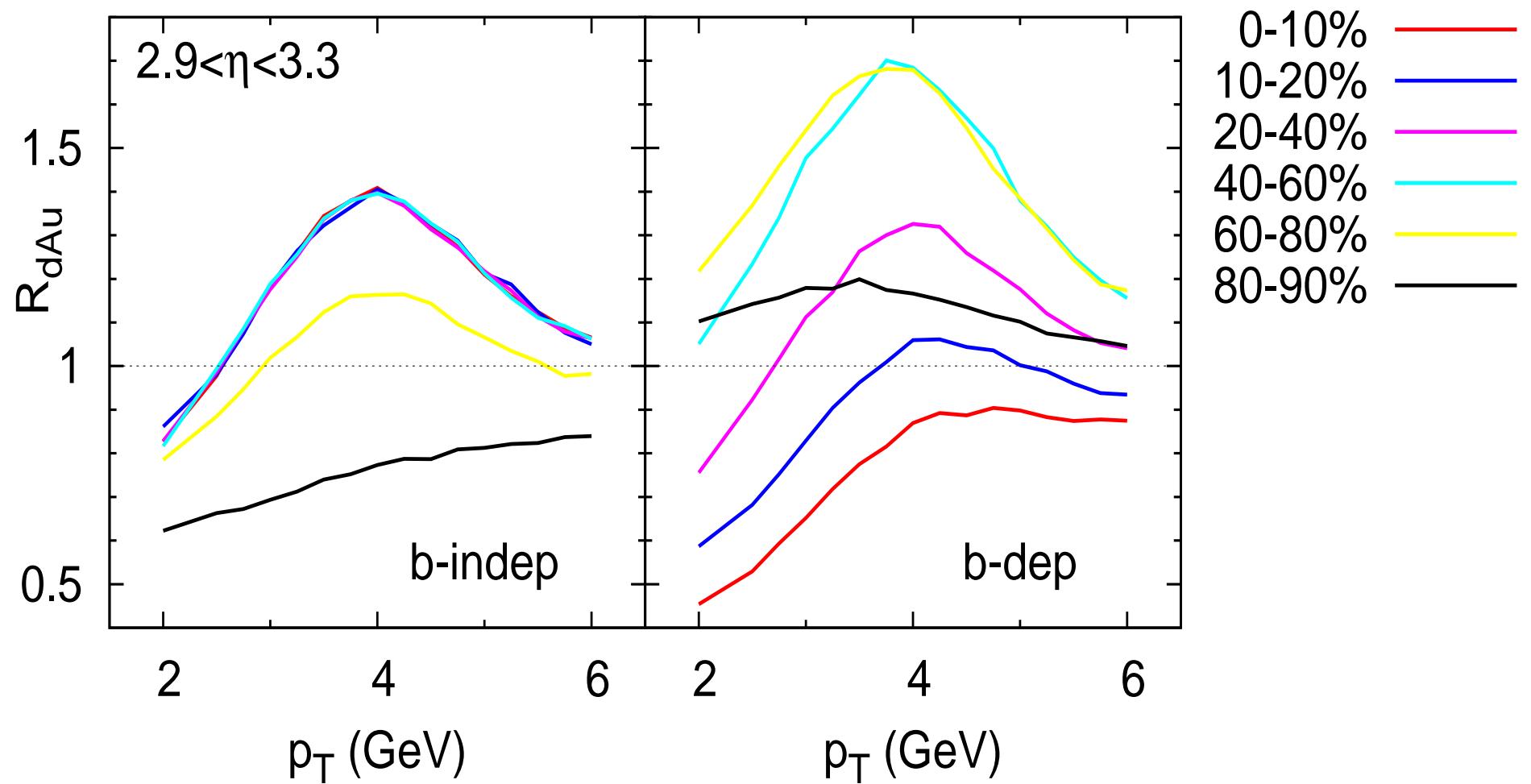
Acta. Phys. Polonica. **B32**, 4069 (2001)

Proc. of ISMD '02 (2003) nucl-th/0212111

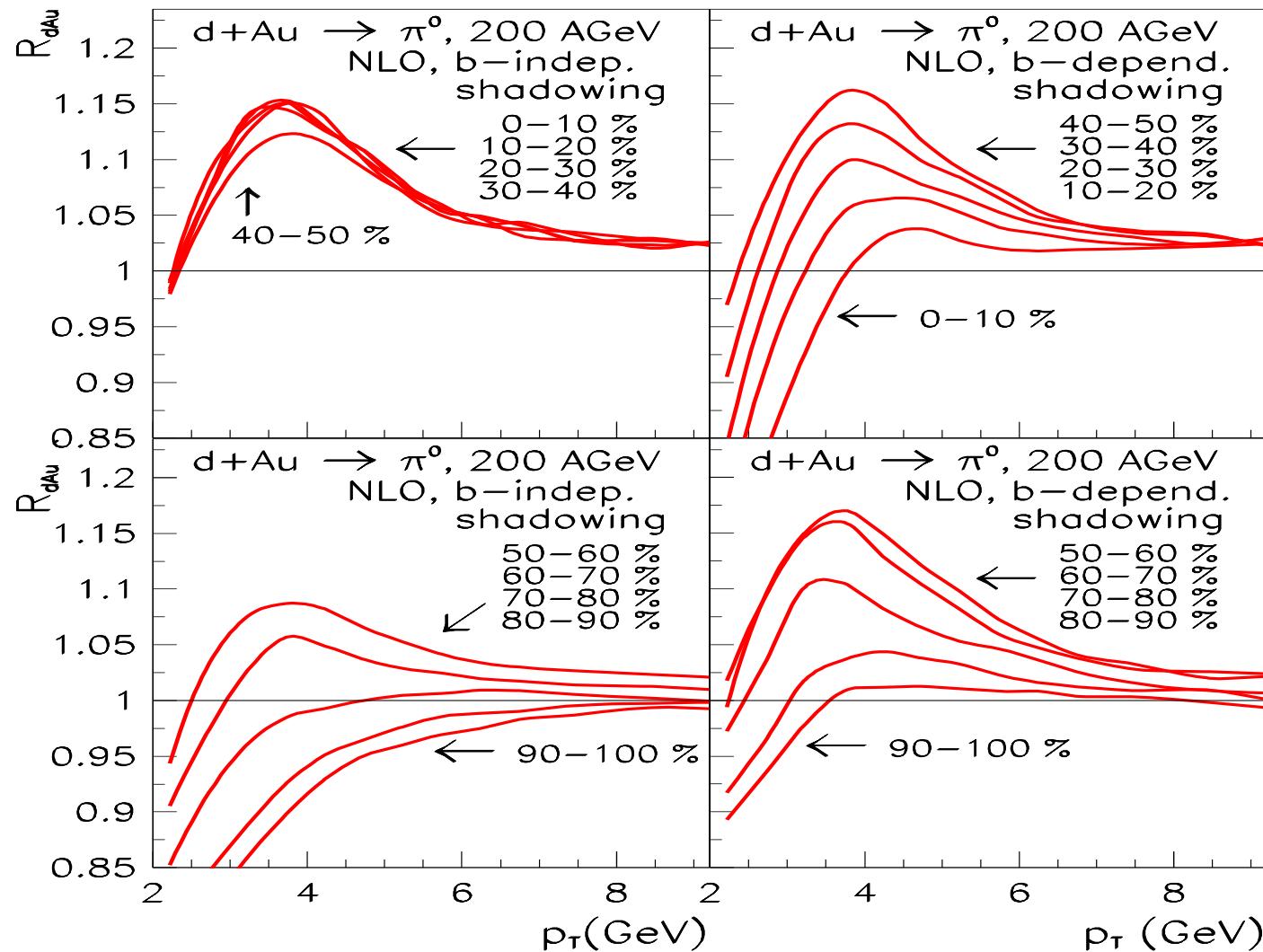
Cumulative probability for dAu collision at different rapidities



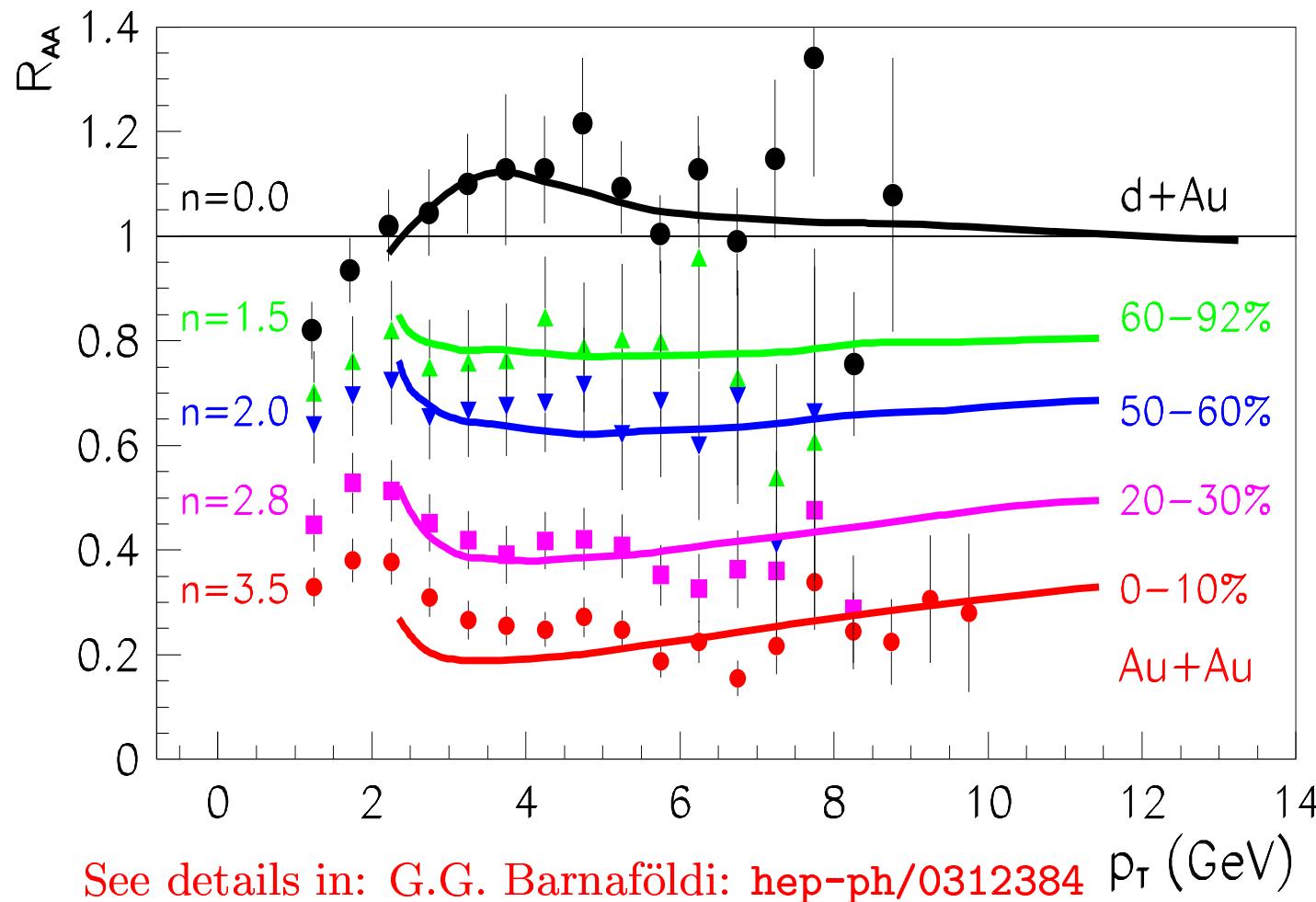
Cronin effect with b-independent (left) and b-dependent (right)
shadowing vs. centrality in dAu collision at BRAHMS



Cronin effect with b-independent (left) and b-dependent (right) shadowing vs. centrality in dAu collision at PHENIX



Jet tomography in $AuAu$ and dAu collision at PHENIX



See details in: G.G. Barnaföldi: [hep-ph/0312384](https://arxiv.org/abs/hep-ph/0312384)

